UCRL- 100194
PREPRINT

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McGraw-Hill Nuclear Publications'
Forum on U.S. Energy Policy & Nuclear Option
Washington, DC
January 31, 1989

January 11, 1989

Lawrence Livermore National Laboratory

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DE89 006234

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ABSTRACT

U.S. energy policy must ensure that its security, its economy, or its world leadership in technology development are not compromised by failure to meet the nation's electrical energy needs. Increased concerns over the greenhouse effect from fossil-fuel combustion mean that U.S. energy policy must consider how electrical energy dependence on oil and coal can be lessened by conservation, renewable energy sources, and advanced energy options (nuclear fission, solar energy, and thermonuclear fusion). In determining how U.S. energy policy is to respond to these issues, it will be necessary to consider what role each of the three advanced energy options might play, and to determine how these options can complement one another.

This paper reviews and comments on the principal U.S. studies and legislation that have addressed fusion since 1980, and then suggests a research, development, and demonstration program that is consistent with the conclusions of those prior authorities and that will allow us to determine how fusion technology can fit into a U.S. energy policy that takes a balanced, long-term view of U.S. needs.

I. INTRODUCTION

Some 15 years after the oil crisis of the 1970s, the greenhouse effect has reawakened public concern over energy. U.S. energy policy must address the economic and environmental issues raised by an electric power system primarily based on fossil fuels. Frank Press, President of the National Academy of Sciences, told a U.S. Senate hearing on global environmental change in July, 1987, "We are indeed facing the prospect of not being able to use fossil fuels in the next century." He added, "I believe when it comes to climatic change as a result of carbon dioxide [buildup] the consequences are uncertain, but they could be so devastating that I think we should start planning at this time for alternative energy sources."

Even apart from the greenhouse effect, conservative estimates of the growth of world population and energy demand lead to many predictions of an energy shortfall (in which energy demand would exceed supply) within 50 to 75 years if we continue to rely on fossil fuels as our major source of energy.[1] A significant fraction of the world's energy must come from other sources by then. Because several decades are required to develop a major new energy production technology and to establish the infrastructure to support it, we must begin that development soon.

Crucial decisions will be made in the 1990s as to the path and timetable for this shift. Renewable energy sources (such as wind, geothermal, and biomass) will play an important part, and conservation will have some impact, but the advanced energy options will be the key to a sustainable future. If those options are to become available in time to forestall economic disruption, it will be necessary to scrutinize their economic viability and environmental liability early in the next century.

It is generally accepted[1] that the rate of electrical energy use will continue to grow in the U.S., that the per capita rate of energy use in all forms in the technically emerging nations will nearly match that of the U.S. within the next 50 to 75 years, and that economic, environmental, or political issues will force a reduction in the use of fossil fuels for electrical energy production by that time. Given these assumptions, there are three viable options for satisfying future energy needs:

1. Develop breeder reactors and advanced nuclear fission technologies, and secure public acceptance by demonstrating safeguards that will make fission energy ultrasafe.

2. Develop solar conversion plants in space and on earth. This could supply a significant fraction of our long-term projected energy needs, but it would require international cooperation on an unprecedented scale.

3. Demonstrate the feasibility of thermonuclear fusion for electrical energy production.

U.S. energy policy should support technical programs for each of these options until it is clear which best meets the needs of national security, the environment, safety, and economics. Although this paper was written for a forum that will explore option 1, the forum's conclusions must fully account for the roles that options 2 and 3 (solar energy and thermonuclear fusion) can play in U.S. energy policy. In the remaining sections of this paper we review and comment on the principal U.S. studies and legislation that have addressed fusion since 1980, and then suggest a research, development, and demonstration program that is consistent with the conclusions of those prior authorities and that will allow us to determine how fusion technology can fit into a U.S. energy policy that takes a balanced, long-term view of U.S. needs.

For readers unfamiliar with fusion technology, Appendix A briefly introduces its concepts, goals, and terminology.

II. FUSION FEASIBILITY: CONCLUSIONS AND RECOMMENDATIONS, 1980-1988

This section summarizes the conclusions and recommendations of a representative subset of major studies, reports, and legislation, published or enacted between 1980 and 1988, that addressed fusion technology capable of electrical energy production.

The March, 1987 Department of Energy (DOE) document "Energy Security"[2] is not summarized here (the document does not consider fusion energy because it is not an in-place electrical energy technology). However, "Energy Security" does contain helpful energy-related data, useful discussions on the economic and security implications of energy, and justification of the need for nuclear fission power. Its description of the roles of government and industry in maintaining viable energy choices for the future can be applied to nuclear fusion as well as to fission. Chapter 7 discusses government-industry interaction.

A. Magnetic Fusion Energy Engineering Act of 1980[3]

Public Law 96-386, the Magnetic Fusion Energy Engineering (MFEE) Act of 1980 (passed by the 96th Congress on October 7, 1980) contained findings and policy for "an accelerated program of research and development of magnetic fusion energy technologies leading to the construction and successful operation of a magnetic fusion demonstration plant in the United States before the end of the twentieth century to be carried out by the Department of Energy." A demonstration plant was defined as a prototype system whose safety, environmental, reliability, availability, and engineering features could be extrapolated to commercial scale but not necessarily one that was economically competitive with alternative energy sources.

In the transition from the Carter Administration to the Reagan Administration, PL 96-386 never became an appropriations act. The continuation of present funding levels will delay demonstration of the commercial feasibility of magnetic confinement fusion (MCF) to around the year 2050. This demonstration could take place by 2020--at the earliest--if funds become available as authorized in the MFEE Act of 1980.

B. National Academy of Sciences Review of the DOE Inertial Confinement Fusion Program (March, 1986)[4]

This review of the DOE inertial confinement fusion (ICF) program was in response to a request from the White House Office of Science and Technology

Policy. Both unclassified and classified versions of the report were prepared. Although the report focuses on applications of ICF to studying the physics and effects of nuclear weapons, one rationale given for supporting the national program was that "ICF may eventually lead to commercial power."

At the time of the report, it was estimated that obtaining results that could support the initiation of an accelerated feasibility program would require five years (1986-1990) at the then (FY86) current level of support ($155 million per year). The main contributors to the target physics program during that period were expected to be the Centurion/Halite program at the Nevada Test Site, which was to provide information on design characteristics of efficient ICF targets using underground nuclear experiments, and the Nova laser program at the Lawrence Livermore National Laboratory, which was to carry out scaled ICF target experiments using a solid state laser driver.

Those results took much less than five years to obtain, however. In 1987, members of the NAS review committee stated that "new experimental results from Centurion/Halite and Nova are sufficiently compelling that DOE is positioned to make a strong case for additional ICF funding." DOE has therefore begun planning studies for the Laboratory Microfusion Facility (LMF), the next major research facility in the national ICF program, whose target physics objectives will include ignition and high-gain studies. The specific type of laser or particle-beam driver for the LMF will be selected in 1991 or 1992.

C. Technical Planning Activity (Executive Summary, January 1987)[5]

This magnetic confinement fusion report states that "the purpose of the Technical Planning Activity (TPA) is to develop a technical planning methodology and to prepare technical plans in support of the strategic and policy framework of the Magnetic Fusion Program Plan (MFPP),[6] issued by DOE in February 1985." The TPA suggested that a balance be maintained between the key technical issues and the overall goal of the program, which was "to establish the scientific and technological base required to assess the economic and environmental aspects of [magnetic] fusion energy."

Four key technical issues were identified: (1) plasma science of magnetic confinement, (2) properties of ignited plasmas, (3) nuclear technologies unique to commercial fusion energy, and (4) material development for enhancing the economic and environmental potential of fusion. Issues 1 and 2 would constitute the main thrust of a fusion energy physics program, and issues 3 and 4 that of a fusion energy technology program; the transition from a predominantly physics program to a predominantly technology program would take place in the late 1990s to early 2000s. The next major U.S. MCF physics research facility planned is the Compact Ignition Tokamak (CIT), a short-pulse ignition experiment that is expected to demonstrate the scientific feasibility of MCF. The remaining nuclear technology issues would be addressed in a follow-on device, the Engineering Test Reactor (ETR). The estimated cost for the MCF program described by the TPA, which includes both the CIT and ETR, is $20 billion for the period 1987-2005.

D. Star Power: The U.S. and the International Quest for Fusion Energy (Office of Technology Assessment, October, 1987)[7]

This extensive report, which primarily assesses the U.S. MCF program, has an appendix on ICF. The report gives a history of magnetic fusion research, describes the science and technology programs, discusses the roles of fusion research as an energy program and as a basic research program, and gives many pertinent tables and graphs. This report could provide the technical background for an updated version of the MFEE Act (described above), except that the executive summary states that "the prospect of future energy shortages alone does not justify a crash program to develop fusion power" [author's italics]. The report does recognize that (for example) environmental factors could influence such a decision. The following excerpt from the executive summary is pertinent:

> "After growing more than tenfold in the 1970s, the U.S. [magnetic] fusion program budget has been declining in recent years. Including the effects of inflation, present funding is about one-half of its peak level of a decade ago. Cuts in the program budget have not resulted from poor

technical performance or pessimistic evaluations of fusion's prospects. Rather, a much-reduced sense of public urgency, coupled with the mounting Federal budget deficit, has tightened the pressure on fusion research budgets.

Choices made over the next several years can place the U.S. [magnetic] fusion program on one of four fundamentally different paths:

1. With substantial funding increases, the U.S. [magnetic] fusion program could complete its presently mapped-out research effort independently, permitting decisions to be made early in the next century concerning fusion's potential for commercialization.

2. At only moderate increases in U.S. funding levels, the same results as above might be attainable--although possibly somewhat delayed--if the United States can work with some or all of the world's other major fusion programs at an unprecedented level of collaboration.

3. Decreased funding levels, or current levels in the absence of extensive collaboration, would require modification of the program's goal and delay U.S. evaluation of fusion as an energy technology.

4. Eliminating funding for fusion research in the United States would foreclose the possibility of developing fusion as an energy technology domestically. Work would probably continue abroad, although possibly at a reduced pace. Resumption of research in the United States at a later date would be possible but difficult."

E. Exploring the Competitive Potential of Magnetic Fusion Energy (DOE Senior Committee on Environmental, Safety, and Economic Aspects of Magnetic Fusion Energy, 1987-1988)[8]

This report by the Senior Committee on Environmental, Safety, and Economic Aspects of Magnetic Fusion Energy (ESECOM) assesses the prospects for

MCF becoming an energy source by the year 2015 with economic, environmental, and safety characteristics that are attractive when compared with those of other energy sources (especially fission). The entire report was not available when this paper was being written; the information summarized below is from the executive summary published in Fusion Technology[8] and given in Appendix B.

The entire ESECOM report can be roughly summarized in a single sentence: "Magnetic fusion energy systems have the potential to achieve costs of electricity comparable to those of present and future fission systems, coupled with significant safety and environmental advantages." Because of its task definition, the report does not assess ICF reactor concepts. Similar ICF studies, narrower in scope than the ESECOM report, have concluded that Cascade,[9] the leading ICF reactor concept, could become competitive with the costs of contemporary coal and fission power plants, and that the Cascade design would be labeled "inherently safe" under current nuclear regulatory guidelines.[10]

Although cost is a primary concern when developing any energy system, it is the combination of economic, environmental, and safety characteristics that will ultimately determine which of the potentially competing technologies--ultrasafe fission, large-scale solar, or fusion--is accepted by the public.

F. National Energy Policy Act of 1988[11]

The National Energy Policy Act of 1988 was a bill (S. 2667) introduced to the 100th Congress by Senator Tim Wirth; it is to be reintroduced on January 25, 1989 to the 101st Congress. The bill, written in response to Congressional concerns over the greenhouse effect, requests (among other things) that the DOE report on the feasibility of fusion. It requests the development of a national energy policy that focuses on conservation and on alternative energy options to fossil fuels. The bill could be considered a step backwards for magnetic fusion because (unlike the MFEE Act of 1980) it does not authorize any funds. Appendix C gives Title VII of S. 2667, which contains the request for a fusion feasibility report, in its entirety.

III. A 1989 SUGGESTION FOR FUSION FEASIBILITY CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations discussed in the previous section remain valid today, except for minor inconsistencies and given the information available at the time and the circumstances surrounding the studies.

It is clear that fusion research is both good science and a worthwhile technology program for a future energy source. Given the long time required to demonstrate the commercial feasibility of fusion, the key policy problem is to determine what parts of the fusion program to support, and at what level. Support for fusion energy waxes and wanes with the political and economic status of world oil supplies. Recommendations have varied between the accelerated programs suggested by the Magnetic Fusion Energy Engineering Act, already described, and the great caution of the European Parliament's recent Scientific and Technical Options Assessment (STOA) report.[12]

The STOA report, assessing the fusion program of the European Economic Community (EEC), concludes that "research in plasma physics should be sustained," but that "a full [fusion energy] feasibility study should be set in motion," and that that study "should be undertaken before acceptance of a [fusion energy] developmental program is recommended to the [European] community."

Stimulated in part by the STOA report, the United Kingdom is considering ending its participation in fusion research at its Culham Research Center by the early 1990s. The Culham Laboratory houses the EEC's flagship fusion facility, the Joint European Torus (JET). The EEC expends 52% of its energy research funds on fusion. The reason most often given by the U.K. for this proposed cut is the "serious imbalance of research funding in the context of current energy economics."

It would be a serious mistake for the U.S. to make such drastic cuts in fusion research. This view is shared by many U.S. science policy leaders, as reported by Miller[13] in his summary of a study by the Public Opinion Laboratory of Northern Illinois University.

Improvements in plasma parameters can be linked to the construction and operation of experimental facilities. The scientific progress exhibited by the larger-scale U.S. fusion experiments--such as Princeton Plasma Physics Laboratory's Tokamak Fusion Test Reactor (TFTR) for magnetic-confinement studies and Lawrence Livermore National Laboratory's Nova laser for inertial confinement studies--has been optimized by theoretical advances in plasma and computational physics. Near-term development plans in fusion research include experiments in the U.S., and in Europe and Japan, to improve plasma performance so as to reach conditions at which the rate of fusion energy production equals the heating power incident on the plasma (that is, breakeven). Progress towards breakeven and the scientific questions remaining to be answered in those facilities are the subjects of ongoing discussions in the fusion community. Next these programs must address ignition--the creation of a self-sustaining, controlled fusion reaction that requires no outside heating of the plasma--which is the final scientific demonstration requirement for fusion. The DOE's Inertial Fusion Division (which oversees the ICF Program) and its Office of Fusion Energy (which oversees the MCF Program) have program plans to define ICF and MCF facilities--known respectively as the Laboratory Microfusion Facility and the Compact Ignition Tokamak--with which to test ignition physics in the laboratory. Each of these facilities has its own unique set of technical challenges and R&D applications; each is conservatively predicted to cost $500 million. The present national fusion research budgets for ICF and MCF are $160 million and $350 million, respectively, and neither budget contains construction funds for the new facilities.

Understanding ignition physics in the laboratory is the only way to demonstrate the scientific feasibility of fusion energy. Scientific progress already made justifies taking this next step; money and scientific effort already expended demand it. At a minimum, the U.S. fusion energy physics program should include the research activities necessary to demonstrate ignition physics in the laboratory. This conclusion is consistent with the conclusions and recommendations discussed in Sec. II.

When the entire U.S. energy policy is formulated, the fusion science programs and their timetables can be weighed against those of alternative energy options. Until then, a minimum fusion energy technology program requires support sufficient to maintain the scientific and engineering talent necessary to respond to the need for a fusion energy infrastructure by roughly 2050, the latest of all estimated dates.

Appendix D gives preliminary conclusions and recommendations circulated in April, 1988 by the American Nuclear Society[14]; for the most part they agree with positions given in this section, and they support greater R&D funding. The funding required for the physics and technology components of the fusion energy science program described in the ANS paper, which might total $1 billion, is roughly double the present annual budget for MCF and ICF research. This level of funding is consistent with the proposed rate of development and demonstration for fusion commercial feasibility by 2020. It does not represent a rate of progress that would imply large cost inefficiencies: a flat budget (even one that accounts for inflation) would probably delay this date to nearer 2050, but would not yield a saving in total cost.

IV. SUMMARY

During the last few years, it has been more and more frequently suggested that the U.S. may be in danger of losing its lead in many technological areas. The U.S. cannot afford to lose its lead in the technology associated with advanced energy options. A U.S. energy policy broad enough to satisfy present and future economic, environmental, and technical issues concerning electrical energy production must support research and development programs necessary to demonstrate a publicly acceptable working system. Until the technology associated with each advanced energy option is demonstrated, it will be impossible to predict the relative risks and advantages of each candidate.

With respect to the feasibility of fusion electrical energy, the scientific challenges are great and the time scale for technological demonstration is long. The sun, the stars, and hydrogen bombs prove that fusion works. The question is whether it is possible to build a fusion power plant that satisfies the public's economic and environmental concerns. Answering this question will require a major national effort costing perhaps $20 billion to $30 billion over the next 30 years. A U.S. energy plan that ignores fusion and address only near-term energy issues would invite long-term energy crises that could have serious implications for U.S. national security, economy, and technological leadership.

ACKNOWLEDGMENTS

Although the opinions expressed in this paper are those of the author, much of the thinking arose from papers by and discussions with numerous colleagues in the ICF and MCF research programs, whose contributions I gratefully acknowledge.

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

APPENDIX A. THE FUSION PROCESS

Nuclear fusion is the source of energy in the sun and stars and in thermonuclear weapons ("hydrogen bombs"). In a fusion reaction, the nuclei of two light atoms collide and fuse to form a heavier atom. In a fission reaction, by contrast, a neutron strikes a heavy nucleus of uranium, causing it to split into fragments. In both processes, nuclear forces convert nuclear matter directly into energy.

One of the most energetic and easiest-to-produce fusion reactions occurs between nuclei of the two heavy forms (isotopes) of hydrogen, deuterium (D) and tritium (T). The two nuclei fuse to form a helium nucleus and a free neutron, whose combined mass is slightly less than that of the initial deuterium and tritium nuclei. According to the Einstein equation $E = mc^2$, which expresses the equivalence of mass and energy, this slight mass loss is converted into a large amount of kinetic energy, most of which is given to the neutron. If its release were properly controlled, this energy could provide a stable source of usable energy. However, controlled fusion is difficult to initiate and maintain. The fuel, a mixture of deuterium and tritium, must be confined at about 100 million degrees C for the fusion reactions to occur. Harnessing fusion is therefore a difficult problem.

The amount of energy available from the fusion reaction is truly remarkable, as evidenced by the energy of thermonuclear weapons. Released in a fusion reactor, the energy from an ounce of deuterium-tritium fuel could supply the needs of a four-person household for about 50 years; it would require the burning of about 300 tons of coal to provide the same amount of energy. The earth's supply of fusion fuel could provide energy for the entire world for many millions of years.

Fusion-energy research is being vigorously pursued at laboratories throughout the world. Reference 15 gives a history of the magnetic-fusion effort in the U.S. from its inception in 1951 through 1978. There are two major approaches, magnetic confinement fusion (MCF) and inertial confinement fusion (ICF). (ICF is also being pursued for nuclear weapons physics studies and for weapon radiation effects simulation.) To achieve breakeven (breakeven is defined as the condition at which the rate of energy production from a fusion plasma equals the incident heating power), both approaches require heating the thermonuclear fuel to a temperature T of about 100 million degrees C (10 keV). At the same time, for efficient burnup of the fuel, both approaches require the achievement of a combination of plasma particle density n and confinement time τ that yields a product $n\tau = 10^{14}$ $cm^{-3}\cdot sec$. This combination of temperature and $n\tau$ requirements is known as the "Lawson criterion."

MCF uses magnetic fields to confine a low-density D-T plasma for a relatively long time (the goal is $n = 10^{14}$ cm^{-3}, $\tau = 1$ sec). By contrast, the inertial confinement fusion process uses a "driver" beam of laser light or particles to compress a thermonuclear fuel pellet, initially about one centimeter in diameter, to about 1000 times liquid density for an extremely short time (here the goal is $n = 10^{26}$ cm^{-3}, $\tau = 10^{-12}$ sec). At such high densities, the fuel burns so rapidly that efficient burnup is achieved before the pellet blows apart and cools.

The improvement in plasma parameters (often expressed in terms of the product $Tn\tau$ of ion temperature, density, and confinement time) can be linked with the construction and operation of experimental facilities. The scientific progress achieved in large-scale U.S. fusion experiments, such as Princeton Plasma Physics Laboratory's Tokamak Fusion Test Reactor (TFTR) for magnetic studies and Lawrence Livermore National Laboratory's Nova laser for inertial studies, has been optimized by theoretical advances in plasma and computational physics. Both TFTR and Nova have exhibited ion temperatures of over 10 keV and have simultaneously achieved $n\tau$ products near 10^{13} $cm^{-3}\cdot sec$. At slightly lower temperatures (a few keV), $n\tau$ products have exceeded 10^{14} $cm^{-3}\cdot sec$ in both devices. Near-term development plans in fusion research include experiments in the U.S., Europe, and Japan to improve the plasma performance to reach breakeven.

$Tn\tau$ values have improved by factors of 100 in both MCF and ICF in the last 10 years. Both MCF and ICF have designs in place for their next major experimental facilities: the Compact Ignition Tokamak (CIT) and the Laboratory Microfusion Facility (LMF), respectively. Each facility is expected to verify the scientific feasibility of high gain and ignition. (High gain is defined as the condition at which fusion energy output is many times the plasma energy input; ignition is defined as the condition at which a plasma produces fusion energy continuously, without further power input.)

Both the CIT and the LMF will test the scientific feasibility of fusion in their respective areas; they will also address their respective technical challenges and demonstrate their R&D applications. Each facility will be followed by another, known as an Engineering Test Reactor (ETR), in which economic and environmental questions will be answered. [The MCF program once had plans for a device known as the Fusion Engineering Device with a similar mission.] The engineering issues of system breakeven, which includes the inefficiencies of the confinement and heating systems, will be evaluated in an ETR.

The MCF communities of the U.S., the European Economic Community, Japan, and the USSR have begun joint studies to evaluate a specific ETR design, the International Thermonuclear Experimental Reactor (ITER). An equivalent effort for an ICF ETR has not begun.

Although the above discussion emphasizes the energy applications of fusion, other applications have been reported recently in the Fusion Applications and Market Evaluation (FAME) Study.[16]

APPENDIX B: EXPLORING THE COMPETITIVE POTENTIAL OF MAGNETIC FUSION ENERGY: THE INTERACTION OF ECONOMICS WITH SAFETY AND ENVIRONMENTAL CHARACTERISTICS (A DOE COMMITTEE EXECUTIVE REPORT)[8]

The Senior Committee on Environmental, Safety, and Economic Aspects of Magnetic Fusion Energy (ESECOM) has assessed the prospects of magnetic fusion energy (MFE) for providing energy with economic, environmental, and safety characteristics that would be attractive compared with those of other energy sources (mainly fission) available around 2015 and thereafter. Eight fusion cases, two fusion-fission hybrid cases, and four fission cases were examined, using consistent economic and safety models, to permit exploration of the characteristics of fusion concepts using a wide range of materials, power densities, power conversion schemes, and fuel cycles. The ESECOM analysis indicates the MFE systems have the potential to achieve costs of electricity comparable to those of present and future fission systems, and that they would have significant safety and environmental advantages.

This conclusion is based on assumptions about plasma performance and engineering characteristics that are optimistic but defensible extrapolations from current experience, and on consistent application of an elaborate set of engineering/economic and safety/environment models to a range of fusion and fission reference cases, with the known characteristics of fission light water reactors as a benchmark. The most important advantages of fusion with respect to safety and environment are the following:

1. High demonstrability of adequate public protection from reactor accidents, based on passive rather than on active safety systems.

2. Substantial amelioration of the radioactive waste problem by eliminating or greatly reducing the amount of high-level waste, which requires deep geologic disposal.

3. Diminution of some important links with nuclear weaponry.

These advantages may be great enough to make a difference in public acceptability of MFE, as compared to fission. Neither the economic competitiveness nor the environmental safety advantages of fusion will materialize automatically. Economic competitiveness depends on attaining plasma and engineering performances that are not yet assured. Achieving the potential environmental and safety advantages depends in large measure on designs tailored to do so and on the use of low-activation materials whose practicality for fusion applications remains to be demonstrated. It is essential that sufficient research and development be devoted early to determining which of a variety of confinement schemes, structural materials, blanket types, and fuel cycle/energy conversion combinations can actually be made practical.

APPENDIX C: TITLE VII--FUSION (NATIONAL ENERGY POLICY ACT OF 1988)[11]

Sec. 801.

(a) Within one year after the date of the enactment of this section, the Secretary shall report to Congress on international collaboration in research, development, and demonstration in technology for the production of electricity from thermonuclear fusion;

(b) The report under subsection (a) shall present a program of research, development, and demonstration in thermonuclear fusion that would ensure by 2010:

(1) a determination of the technological feasibility of thermonuclear fusion as a source of electric power; and
(2) in the event that such feasibility is determined, the development of a design of a prototype commercial fusion reactor, accompanied by cost estimates and specifications sufficient to permit bids for construction of the reactor;

(c) the report shall include:

(1) an assessment of the actions needed and the funds that would be necessary to achieve the goals of the program under subsection (b);
(2) an analysis of funds that would be provided by the United States under appropriate scenarios for international collaboration in a program of thermonuclear fusion research, development, and demonstration that would achieve such goals;
(3) a review and analysis of the major obstacles to international collaboration in such a program; and
(4) the Secretary's recommendations for additional legal and budgetary authority required to implement the preferred scenario among those considered under paragraph (2).

APPENDIX D: CONCLUSIONS AND RECOMMENDATIONS FROM A STATEMENT ON FUSION ENERGY BY THE AMERICAN NUCLEAR SOCIETY[14]

A report made available April 1988, by the American Nuclear Society makes a strong case for support of fusion research and development. Its conclusions and recommendations are given below.

CONCLUSIONS

The long-term benefits of fusion energy are sufficiently great to warrant a sustained national and international effort aimed at advancing fusion science and technology at least to the point where commercial potential can be accurately assessed in quantitative economic and environmental terms.

Recent scientific progress in fusion energy has been sufficiently encouraging to warrant proceeding with an enhanced fusion engineering program.

Assuming continuing success in physics and technology programs, it appears technically feasible to develop fusion energy to the commercial state well within the first half of the next century; however, an enhanced research and development program will be required.

RECOMMENDATIONS

It should be a national goal to operate a fusion engineering test reactor (possibly on the basis of international cooperation) before the turn of the century to determine the feasibility and role of fusion as a long-range energy strategy. Smaller ignition/burn experiments like the Compact Ignition Tokamak (planned for construction at the Princeton Plasma Physics Laboratory) could help achieve this goal.

It should be a national goal of the inertial confinement fusion program to move toward a high-gain Laboratory Microfusion Facility (LMF). An LMF would be a national resource for studying defense applications of inertial fusion technology and would provide the data required to build an engineering test reactor for energy applications. Such a facility should be planned.

As part of the fusion research and development effort, the fusion program should include a sufficiently broad base of research, technology, and engineering to permit promising alternative confinement concepts and supporting technologies to be developed. This work should include conceptual designs of more attractive fusion power reactors. As clearer directions emerge, appropriate narrowing of the program options should be considered.

The present state of the fusion program warrants increased study of the possible practical applications of fusion energy. Potential applications, such as electric-power, fissile-fuel, and synthetic-fuel production, should be studied.

Cooperative efforts in the fusion program should be intensified with the electric utilities and with industry. Such efforts will help to guide the development of fusion energy and to assure that fusion contributes to meeting national energy needs. Efforts should be continued to encourage international cooperation* in fusion research and development.

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* Author's note: Before entering into international cooperation, the U.S. must consider its national security interests. Reference 17 discusses the prospects for international cooperation.

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